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WORKING PAPER

ALIGNING ELECTRICITY TRANSMISSION AND DISTRIBUTION INVESTMENTS WITH A PARIS AGREEMENT PATHWAY

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EXECUTIVE SUMMARY

Highlights

- To achieve the goal of the Paris Agreement, all financial flows will need to be made consistent with low greenhouse gas (GHG) emissions and climate-resilient development.
- It is especially critical that energy-sector infrastructure investments are Paris-aligned, given the large carbon lock-in potential of investments and the scale of investment needed in the coming years.
- While there have been efforts to assess the alignment of energy-sector investments by the multilateral development banks (MDBs), transmission and distribution (T&D) investments have simply been considered conditional (i.e., aligned under certain conditions) with no further project-specific evaluation.
- We propose a simple methodology and decision tree for assessing the Paris alignment of T&D investments at the project level.
- Our long-term goal is not only to provide a methodology that can be used to screen investments externally at the project level, but also to mainstream this methodology into MDBs' investment decisions and energy portfolios.

CONTENTS

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Context

Parties to the Paris Agreement are committed to the goal of keeping global warming to "well below" 2°C. Parties committed to "making finance flows consistent with a pathway towards low GHG emissions and climate-resilient development (Article 2.1c) (UNFCCC 2016)." It is imperative that all public and private capital be shifted away from "brown" to "green" finance.

It is especially critical that energy-sector infrastructure is Paris aligned, given the large carbon lock-in potential of investments and the scale of investment needed in the coming years in the developing world. The Global Commission on the Economy and Climate estimates that US$6 trillion a year of infrastructure investments will be needed by 2030, of which 30 percent is in the energy sector (Global Commission on the Economy and Climate 2016). Low-carbon investments in the energy sector will be especially important in the developing world, because more than 50 percent of total investment is currently devoted to the energy sector (Global Commission on the Economy and Climate 2016).

About This Working Paper

The purpose of this paper is to propose a credible and rigorous methodology for assessing Paris Agreement alignment of electricity transmission and distribution (T&D) investments. T&D is a subsector where there has been limited methodological development. Our goal is to provide a methodology to screen investments at the project level, rather than quickly assess the alignment of a portfolio. However, applied in aggregate, the methodology would allow one to assess the overall alignment of a portfolio of T&D investments. This paper was informed by a technical workshop, "Alignment of Electricity T&D Investment with a 2° Pathway," which the World Resources Institute convened in Washington, DC, on March 27, 2018. The workshop brought together 11 external experts from across the globe, including emerging-market countries (Brazil, Chile, China, India, and South Africa), with a varied expertise.

While there have been some recent efforts to assess the alignment of energy-sector investments with two-degree pathways, previous assessments have simply considered T&D investments as conditional. Other finance tracking efforts, although not explicitly focused on alignment with 1.5/2°C, have generally considered T&D to be climate or clean-energy finance if the investment facilitates renewable energy and/or reduces energy use or electricity losses.

A specialized methodology for T&D investments is needed to fully appraise the alignment of energy-sector investments. First, T&D is very prominent in MDBs' energy portfolios. For example, T&D projects constituted around half the total volume of financing and about 40 percent of the total number of energy projects for both the ADB and World Bank (Christianson et al. 2017). Second, many MDB T&D investments are stand-alone projects separate from electricity generation projects.

Our Findings

We have proposed a methodology to assess Paris alignment of T&D investments based on three factors: (1) the need to adopt a systematic approach that assesses T&D in the context of a larger energy system, (2) the imperative of factoring in high-emissions lock-in risk, and (3) the importance of considering broader, country-specific climate plans and strategies. Our approach is a project-level screen, with each project component analyzed separately (Christianson et al. 2017). Figure ES-1 describes our decision tree for assessing Paris alignment.

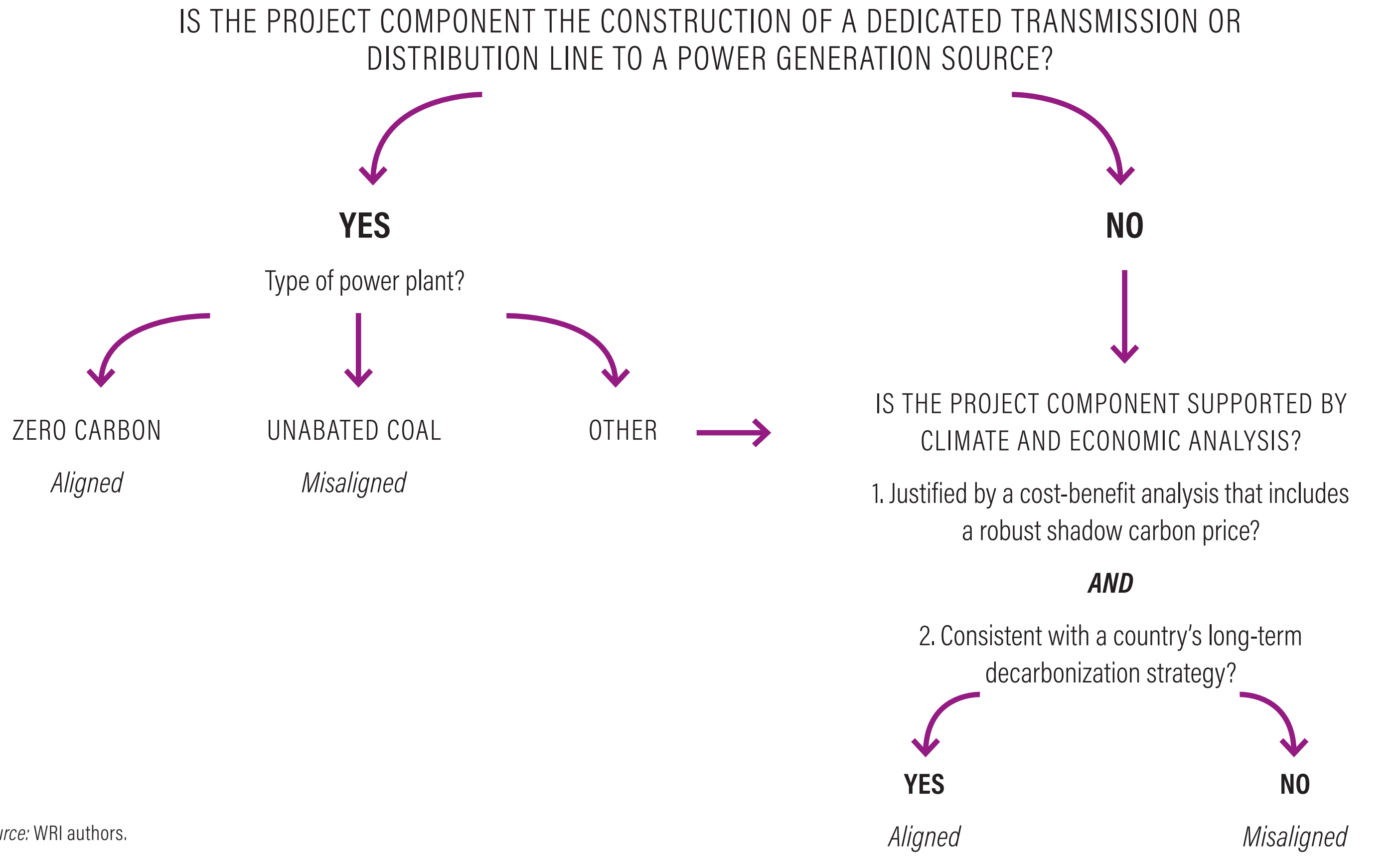
T&D project components can be classified into only two types. The first type involves T&D technologies that support a particular power generation source (e.g., dedicated transmission or distribution lines). The second involves general T&D technologies that are not associated with a specific source. The latter category includes the vast majority of T&D investments.

With the exception of dedicated T&D lines to specific power plants, T&D technologies by themselves are carbon-emissions agnostic and can carry power from any source. While certain T&D technologies will need to be scaled up to enable a high degree of integration of renewables or more distributed sources, such as high-voltage direct current (HVDC) transmission lines or smart grid technologies, both of these technologies can also convey fossil power.

The Paris-alignment of a T&D technology type depends on whether it supports a power plant that is zero-carbon *(aligned)*, **unabated coal (without carbon capture and storage)** *(misaligned)*, **or other generation.** The latter case would need to undergo a two-step climate and economic analysis (below).

In the case of T&D investments that don't support a particular power source or support fossil fuel

Figure ES-1 | **Schematic of the Methodology to Assess Alignment of T&D Investments**



Source: WRI authors.

generation other than unabated coal, alignment is contingent on two factors. Our methodology calls for justification with a robust shadow carbon price and consistency with a country's long-term decarbonization plans for the electricity sector. First, a robust shadow carbon price should be applied, consistent with the recommendations of the High-Level Commission on Carbon Prices (\$40–80/tCO_2 by 2020 and \$50–100/tCO_2 by 2030) for achieving the Paris temperature target (Carbon Pricing Leadership Coalition 2017). The shadow carbon price needs to be incorporated in cost-benefit analysis, and the investment should have the highest net present value of any project alternative. Second, every T&D investment component or overall project would need to explain credibly how the project will help facilitate long-term decarbonization of the electricity sector. The T&D component would be assessed against either a long-term strategy that countries have been invited to submit as part of the UNFCCC process (UNFCCC 2016) or a clear sectoral plan for decarbonizing the electricity sector by 2050. These two criteria—both near-term and long-term analysis—allow for the possibility that certain development priorities, such as energy access, might allow for increased GHG emissions, as long as countries have longer-term plans to "bend the emissions curve" and move toward decarbonization.

In the absence of either the incorporation of shadow carbon pricing into cost-benefit analysis or a long-term decarbonization plan, T&D investments not directly supporting renewable energy would be classified as misaligned. This is the default classification until more information is provided. Few countries have submitted long-term decarbonization strategies, and all the MDBs have yet to incorporate shadow carbon pricing in decision-making and make the analysis publicly available. However, based on recent developments in carbon pricing and the expectation that many countries will submit long-term strategies by 2020, we do believe trends are in the right direction. Our conservative approach will hopefully generate more impetus for development finance institutions (DFIs) to incorporate a shadow carbon price in cost-benefit analysis and work with developing countries to develop long-term decarbonization plans.

This methodology is focused on project-level screening of climate-change mitigation impacts of T&D. In aggregate, this project-level screening does allow one to assess the overall T&D portfolio of a DFI, but there are other approaches to portfolio assessment that could be employed. For example, one fairly quick way to assess T&D investments at the portfolio level is to adopt a *pro rata* approach, where alignment is based on the current electricity mix in any country, because the alignment of T&D is a function of the degree to which electricity generation is aligned. In this case, the percentage of the aligned T&D investments in any country would be equal to the percentage of electricity generation that is zero-carbon. However, this *pro rata* approach only gives a static picture of a country's energy past and doesn't consider a country's rate of change and progress on a Paris pathway. Moreover, one DFI's portfolio in any country may only be a small subset of the larger public and private investment. Also, our assessment only answers a limited question as to whether a T&D investment is aligned with the Paris Agreement in terms of mitigation, and climate resilience is not factored into the assessment. We recognize that there are other political and socioeconomic considerations for investment decisions besides climate change; however, it should be emphasized that climate change constrains possible development paths and that all of the 17 Sustainable Development Goals are directly or indirectly related to climate action (United Nations 2018).

Recommendations

DFIs should ensure that a shadow carbon price is incorporated in cost-benefit analyses and has a determinant impact on project approval. These institutions should begin to disclose the cost-benefit analyses of both the selected project and alternatives in the project documents. Moreover, the MDBs should ratchet up ambition and adopt prices in accord with the ranges put forth by the High-Level Commission on Carbon Prices (Hawkins and Wright 2018).

DFIs should help recipient countries develop more robust climate-change commitments, including long-term decarbonization plans that include short-term, medium-term, and long-term quantified targets across sectors. DFIs need to justify in publicly available documents how T&D investments are congruent with these long-term decarbonization plans.

I. INTRODUCTION

To have a likely chance (i.e., ≥ 66 percent) that mean global warming stays below 2°C relative to pre-industrial levels, atmospheric concentrations of GHGs will need to stay around 450 ppm CO_2e. This would entail reducing GHG emissions by 40 to 70 percent globally in 2050, compared to 2010, and emissions near zero $GtCO_2$e or below in 2100 (IPCC 2014). The decarbonization (i.e., reducing the carbon intensity) of electricity generation is one essential pillar of long-term, cost-effective climate change mitigation. In the majority of integrated assessment modeling scenarios that achieve low-stabilization levels (430–530 ppm CO_2e[1]), the decarbonization of the electricity sector occurs more rapidly than the rest of the energy system; the share of low-carbon electricity increases from about 30 percent today to 80 percent by 2050 (Bruckner et al. 2014). By 2100, fossil fuel–based electricity without carbon capture and storage (CCS) is phased out entirely (Bruckner et al. 2014). Likewise, under a 1.5°C scenario, there's a complete phase-out of unabated fossil fuels for electricity by 2050, with electricity primarily generated from solar and wind (Rogelj et al. 2018).

To reduce the risks and impacts of climate change, the Parties to the Paris Agreement have agreed to hold the increase in mean global temperature to "well below" 2°C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5°C (Article 2.1a) (UNFCCC 2016). To achieve this in part, the countries have committed to "making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development" (Article 2.1c).

Thus, it is imperative that public and private capital be shifted away from "brown" to "green" investments in all sectors in the economy. It is critical that energy sector infrastructure, including electricity generation, transmission, and distribution, be aligned with scenarios that limit global warming to well below 2°C, given the large carbon lock-in potential of investments and the scale of investment needed in the coming years. The Global Commission on the Economy and Climate estimates that $6 trillion a year of infrastructure investments will be needed by 2030, of which 30 percent is in the energy sector (Global Commission on the Economy and Climate 2016). Low-carbon investments in the energy sector will be especially critical in the developing world where a greater proportion of infrastructure investment is already directed toward energy than in advanced economies. In low-income countries, more than 50 percent of total investment is currently devoted to the energy sector (Global Commission on the Economy and Climate 2016).

In this paper, we first review existing methodologies for assessing alignment of energy investments, including approaches to categorize T&D investments. We then give a brief survey of T&D projects at two MDBs and present our own draft methodology for assessing alignment of T&D. Our goal is to provide a methodology to screen investments at the project level, rather than quickly assess the alignment of a portfolio. However, applied in aggregate, the methodology would allow one to assess the overall alignment of a portfolio of T&D investments. While our focus is on alignment of MDB investments, given our previous work (Christianson et al. 2017), our methodology can be applied to other DFIs, such as national development banks. We conclude by discussing implementation of this methodology and its limitations and offering some insights on T&D in the context of the grid of the future.

This paper was informed by a technical workshop, "Alignment of Electricity T&D Investment with a 2°C Pathway," which WRI convened in Washington, DC, on March 27, 2018. The workshop brought together 11 external experts from across the globe, including emerging-market countries (Brazil, Chile, China, India, and South Africa) with a variety of disciplinary expertise, such as power systems engineering, electricity systems modeling, renewable energy and low carbon energy planning, energy economics, electricity sector investments, electricity regulation, and climate finance. We circulated a draft methodology to participants prior to the workshop and subsequently made two revisions of this paper based on workshop feedback and written comments from the technical experts and other WRI and external experts.

II. EXISTING METHODOLOGIES FOR ASSESSING ALIGNMENT OR CLIMATE COMPATIBILITY IN THE ENERGY SECTOR

There have been some recent efforts to assess the alignment of energy-sector investments with two-degree pathways (Höhne et al., 2015a, 2015b, 2017). Based on reviews of integrated assessment and energy-sector models and mitigation scenarios, Höhne et al. (2015a, 2015b, 2017) categorize each investment area/technology into one of four categories: **2°C compatible** (fully aligned across all scenarios), **conditional** (aligned only under certain conditions in all scenarios), **ambiguous** (aligned in some scenarios), and **misaligned** (consistently misaligned with 2°C in all scenarios). For energy supply, renewable energy is classified as fully 2°C compatible, while new coal-fired power plants with unabated emissions are classified as misaligned. The ambiguous category includes biofuels, bioenergy with carbon capture and storage, large hydropower, and nuclear, while the conditional category includes natural gas–fired power plants and energy and T&D infrastructure. For the latter, no further guidance is provided, although the authors do provide the following potential analyses that can be applied after the initial screening for all projects not deemed as misaligned:

- **Economic evaluation**. The analyses of the economic costs and benefits would include the application of a shadow carbon price.
- **Development evaluation**. This assessment would include an evaluation of whether the project is in accord with national climate or low-carbon development strategies; for example, Nationally Determined Contributions (NDCs).
- **ESG evaluation**. This would include an appraisal of a project's social, environmental, and governance risks and impacts.

Christianson et al. (2017) used the 2°C alignment methodology of Höhne et al. (2015a, 2015b, 2017) to classify energy-sector projects of the World Bank, International Finance Corporation (IFC), and the Asian Development Bank (ADB), expanding the set of technologies in each category.[2] Where projects had multiple components, the authors grouped the projects based on the following criteria:

- containing at least one misaligned component = **misaligned**
- containing a controversial component but not a misaligned component = **controversial**
- containing a conditional component but not a controversial or misaligned component = **conditional**
- containing only aligned components = **aligned**

For the purposes of the project screening analysis, the authors classified as electricity T&D all projects that addressed large portions, or the entirety, of the grid. Power plant–specific T&D infrastructure was classified as a power supply investment, the alignment determined by the fuel type. T&D projects were classified as **conditional**, and no further guidance on alignment was provided (in lieu of more methodological refinement), although the authors of those studies put forth the following set of questions that could be asked for conditional projects (Höhneet al. 2015a, 2015b, 2017):

- Is the project viable with a shadow carbon price (assuming the price is set at a high level that is compatible with 2°C scenarios)?
- Does the project fit into a path toward zero $gtCO_2$/kWh in 2050?
- Is the project consistent with the country's climate strategy (NDC or other decarbonization strategy) when considering lifetime, operation mode, fuel source, and capacity requirements?
- Would the investment switch to the misaligned category when ratcheting up domestic ambition in the context of the Global Stocktake or other future climate policy development?

It is also important to acknowledge how finance tracking methodologies for climate and fossil fuel finance consider energy investments. The MDBs and the International Development Finance Club (IDFC) have developed the Common Principles for Climate Mitigation Finance Tracking (MDBs and IDFC 2015), setting out common definitions and guidelines for tracking mitigation finance. They classify projects as mitigation finance based on a positive set of activities (IDFC 2015; AfDB et al. 2017). In the energy sector, all projects in these subsectors are classified as climate finance: renewable energy, low-carbon and energy-efficient generation (includes a shift to a less carbon-intensive fossil fuel, excluding coal), and energy efficiency. Other energy-related projects are counted as climate finance, such as carbon capture and storage (CCS), and those that reduce fugitive emissions. In terms of electricity T&D, the methodology considers as contributing to climate change mitigation all new transmission systems and related infrastructure that seek "to facilitate the integration of renewable energy sources into the grid." The retrofitting of transmission lines, substations, and/or distribution systems are also considered as climate finance if there is a reduction of energy use and/or technical losses (unspecified as to whether this is over the short or long term) (AfDB et al. 2017). It should be noted that the Common Principles for Climate Mitigation Finance Tracking were developed before Paris and were not formulated explicitly to be aligned with 2°C.

Similarly, Oil Change International has developed a methodology to track fossil fuel subsidies (Oil Change International 2017). Whether an electricity T&D project is classified as clean energy, fossil, or other fuel finance is simply dependent on what specific source of energy the T&D investment supports; those that cannot be linked to specific energy sources are classified as other."

Last, the Climate Bonds Initiative has developed a series of climate bonds standards for clean energy, including solar, onshore wind, and marine renewable energy (Climate Bonds Initiative 2018). Only transmission infrastructure and support facilities dedicated to serve renewable energy (e.g., inverters, transformers, energy storage systems, and control systems) are considered acceptable investments under these clean energy standards.

III. T&D INVESTMENTS AND TECHNOLOGY TYPES

T&D in Multilateral Development Banks

Before we advance a set of criteria to assess electricity T&D investments for MDBs and other DFIs, it is worth examining the nature of MDBs' current investments in T&D. T&D investments constitute an important share of MDB energy-sector investments. For example, T&D projects constituted around half the total volume of financing and about 40 percent of the total number of energy projects for both the ADB and World Bank in the Christianson et al. (2017) study.

We reviewed 35 T&D projects approved in calendar year 2016 at the World Bank and ADB that were previously tagged as having at least one T&D component (Appendix A) (Christianson et al. 2017). The most common stated goals of the T&D projects reviewed are supporting climate-change policies, reducing system losses, and improving system reliability. Of the 35 projects examined, the most common project components are micro grids (both fossil fuel–and renewable energy–powered), followed by construction of distribution lines, distribution network upgrades, grid expansion (e.g., to expand energy access), and transmission network upgrades. Very few projects included the construction of dedicated transmission lines for power plants, but some electricity generation projects would also include the construction of dedicated transmission/distribution lines. Christianson et al. (2017) classified these projects as power supply, not T&D, investments.

Almost all of the projects have components where the fuel type was not specified or was not clear from the project documents. In these cases, the T&D project component may support the grid for the entire country or a large region, and the power generation sources may be varied. This is especially true for projects that include components for grid expansion and upgrades or the construction of distribution lines. However, a significant number of project documents describe components that explicitly mention the electricity generation type for the grid (or the power plant type in the case of small plants connected directly to distribution lines) that the T&D component is facilitating: fossil fuels, mixed/hybrid, and renewable energy.

T&D Alignment and Specific Technology Types

There are certain types of T&D technologies that will need to be scaled up to enable a high degree of integration of renewables or more distributed sources. High-voltage and ultra-high-voltage transmission lines are particularly useful in transmitting power over long distances where renewable sources (e.g., remote onshore and offshore wind farms, concentrated solar power in desert areas) are far from population centers. HVDC can connect distances of more than 2,000 miles and transmit up to three times the power of alternating current (AC) systems (Navigant Research 2018). China, for example, is investing in an ultra-high-voltage AC and DC system to, in part, facilitate wind power capacity of 140 GW by 2020 (Kyoichi Uehara et al. 2015). Over the next 15 to 20 years, high-voltage and ultra-high-voltage transmission infrastructure will likely play a large role in the massive amount of renewable energy generation capacity that is planned around the world (Kyoichi Uehara et al. 2015), although distributed renewables do not need this infrastructure. However, high-voltage and ultra-high-voltage transmission lines can carry electrons from any source (and thus, they do not solely enable renewable energy), while integration of renewable energy will also require traditional transmission infrastructure.

Smart grid technologies—various digital communications, information management, and control technologies (Table 1)—will be needed to integrate renewables into the grid at the levels that are necessary for deep decarbonization of the electricity sector. Capacity penetration levels above 30 percent are considered high for renewables and will usually necessitate the use of smart grid technologies to ensure grid reliability (Kyoichi Uehara et al. 2015). However, smart grid technologies have a suite of other benefits, including a more efficiently operating electricity system and reduced operational costs (Kempener et al. 2013).

Therefore, except for dedicated T&D lines to specific power plants, T&D technologies by themselves are "carbon-emissions agnostic" in that they can carry power from any source, irrespective of carbon intensity.[3] Electrons are electrons, and both smart grids and HVDC can also facilitate fossil power. T&D infrastructure is certainly essential to decarbonize electricity systems: T&D projects that strengthen the grid and improve reliability may enable fossil fuel generation in the short term (~ next 5–10 years) but may also be essential for providing the long-term (2050 and beyond) grid capacity needed for a long-term shift to renewables.

Table 1 | **Summary of Smart Grid Technologies**

TECHNOLOGY	EXPLANATION	PROBLEM MITIGATED
Advanced Metering Infrastructure	Meters that typically measure energy usage with higher time resolution and can engage in two-way communication with utilities, including sending usage data back	Lack of distribution monitoring; outage detection and location; energy conservation; energy theft
Advanced Electricity Pricing	Pricing programs that try to make consumer prices more accurately reflect real-time production costs such that consumers' consumption usage shifts to times when electricity is less expensive	High peak loads; load shedding; outage frequency
Demand Response	Techniques (direct, voluntary, or dynamic) for reducing electric system loads during times of peak electricity usage or when renewable production drops	High peak loads/prices; load shedding; outage frequency
Distribution Automation	Automated control techniques that optimize the performance of power distribution networks	Inefficiency; voltage regulation; outage frequency and duration; distribution maintenance costs
Renewable Resource Forecasting	Making prediction of solar and wind output using weather prediction models	Reliability issues and cost of wind/solar variability; voltage and frequency regulation; optimal generation scheduling and dispatch to reduce cost
Smart Inverters	Used to interface with renewable sources to mitigate transient grid voltage fluctuations that can occur	Power quality; voltage/frequency regulation; undesired inverter tripping offline; increasing the amount of renewable energy that can be integrated into the grid
Bulk or Distributed Storage	Electricity storage can provide grid flexibility when dealing with variable renewable sources. In contrast to bulk storage, which can provide large amounts of power (MWs) over hours, distributed storage can provide smaller amounts (kW to MW) over shorter periods of time (milliseconds to minutes)	Voltage/frequency regulation; power ramps; T&D upgrade deferral; energy arbitrage; grid reliability improvement
Micro Grids	Can be completely disconnected from the main grid on temporary or permanent basis and operate autonomously	Power outages; power quality; solar/wind variability; high peak loads/prices; electricity access; rural electrification remote from existing grids
Virtual Power Plants (VPP)	Aggregation of energy resources that need not be co-located geographically but still can operate independently of the grid	Solar/wind variability; high peak loads/prices; demand response

Source: Kempener et al. 2013.

IV. PROPOSED METHODOLOGY FOR ASSESSING ALIGNMENT OF T&D INVESTMENTS

Given the prominence of T&D investments in MDBs' energy portfolios and the fact that many T&D investments are stand-alone projects separate from electricity generation projects, a specialized methodology for T&D investments will help to fully appraise the alignment of energy-sector investments. Based on the survey of typical T&D projects at the MDBs, our review of the alignment literature, and specific T&D technologies discussed above, here we present our methodology for assessing Paris Agreement alignment of T&D investments.

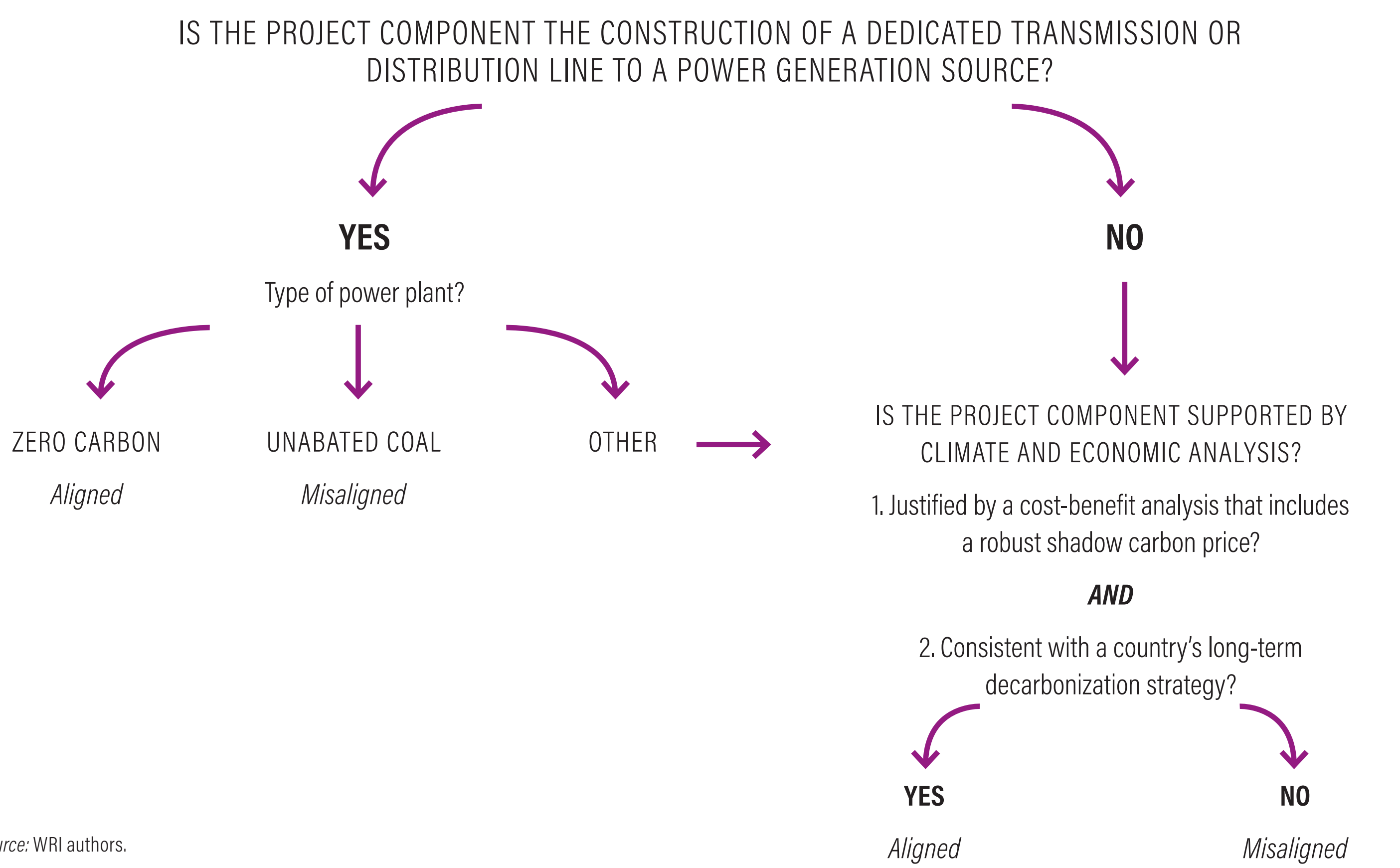
Three factors have informed our methodology: (1) the need to adopt a systematic approach that assesses T&D in the context of a larger energy system, (2) the imperative of factoring in high-emissions lock-in risk, and (3) the importance of considering broader, country-specific climate plans and strategies.

Our approach is a project-level screen, with each project component analyzed separately (Christianson et al. 2017). Our goal is to articulate an approach that is economical, practical, and applicable across not only the MDBs but other DFIs, based on project documents. Figure 1 shows the steps of our alignment methodology, structured as a decision tree.

We classify T&D project components into only two types:

- **T&D technology types that clearly support a particular power generation source**. This category includes the construction of dedicated transmission and distribution lines for a specific power generation source. Whether the project component is congruent with a Paris pathway is a function of whether the power plant is zero-carbon[4] (**aligned**), unabated coal (without carbon capture and storage) (**misaligned**), or other.[5] The latter category would undergo the two-step climate and economic analysis below.

Figure 1 | **Schematic of the Methodology to Assess Alignment of T&D Investments**



Source: WRI authors.

The case of natural gas–fired plants deserves some further discussion. Ultimately, whether natural gas as a whole is aligned with Paris is dependent on the rates of methane leakage from pipelines (Brandt et al. 2014) and whether it can serve as a bridge and complement to more variable renewable energy sources, rather than simply locking in emissions for the next 30 to 50 years. Emissions from projected natural gas produced through 2050 from planned development in G20 countries alone could consume nearly two-thirds of a carbon budget that offers a 50 percent chance of limiting global warming to below 1.5°C (Stockman et al. 2018). By 2050, under a 1.5°C scenario, there is a complete phase-out of unabated fossil fuels for electricity by 2050 (Rogelj et al. 2018). While dedicated T&D lines to natural gas–fired plants are not characterized initially as misaligned, to be consistent with a country's long-term decarbonization strategy, there must be a plan for phase-out of the plants by 2050.

- **General T&D technologies that do not support a particular power generation source**. Our second category includes all other T&D technology types that do not support a particular power generation source and would include general T&D technologies, including investments in new or upgraded traditional transmission lines for several power stations or across the entire grid, substations, transformers, converters, metering, capacity building, and business model strengthening for utilities. This would include the vast majority of T&D investments. We propose that, to be considered **aligned**, the project component would need to be supported by a two-step climate and economic analysis:

i. Justification with a shadow carbon price[6]

This would involve using a robust carbon price in a social cost-benefit analysis (CBA). This analysis is more near-term, factoring in climate change costs over the life of the project. While models differ on the carbon price trajectory needed to keep warming to below 2°C and estimates vary on the social cost of carbon (US IAWG 2016), the High-Level Commission on Carbon Prices concludes that the explicit carbon-price level consistent with achieving the Paris temperature target is at least \$40–80/tCO_2 by 2020 and \$50–100/tCO_2 by 2030, but would likely vary across countries (Carbon Pricing Leadership Coalition 2017).[7]

In general CBA, the profitability of the project is determined by calculating the net present value (*NPV*), which is the sum of the benefits (*B*) minus the capital and operating costs (*C*) and external costs (*E*) for each year *t* over the lifetime of the project (*T*):

$$NPV(r)= \sum_{t=1}^{T} \frac{B_t - C_t - E_t}{(1 + R)^t} - C_o$$

where C_o is the initial capital cost, C_t is the operating cost, and *r* is the discount rate. Potential external costs would include the cost of CO_2 emissions (calculated at social cost of carbon (\$/tCO_2e[8])) and the costs of local air pollution. NPV is expressed in monetary units (e.g., U.S. dollars). The MDBs already commonly do CBA in project evaluation.

If the NPV is greater than zero, the project is profitable. **However, a positive NPV is not sufficient, and the alternative with the highest NPV (including a baseline or status quo) inclusive of a carbon price should be selected for implementation**. (In the case of power generation, the result is often expressed as the cost per unit of power (e.g., \$/MWh), also known as the levelized cost of electricity). There certainly may be costs and benefits that are difficult to monetize, but some important development considerations, like the benefits of providing energy access, should be quantifiable.

In many cases, a T&D investment is just one component in a larger electricity sector project, where the core project activity may be electricity generation. In this case, the CBA would be applied to the entire project and would include the emissions associated with electricity generation. However, in some instances the T&D investment is a stand-alone project, in which case, the CBA would only be conducted on the T&D project and would include only those emissions associated with T&D. Many DFIs have already agreed to include Scope 1 GHG emissions (direct emissions from the financed project) and Scope 2 (GHG emissions during generation of electricity or heat) in GHG accounting (Ranganathan et al. 2004), while Scope 3 has been optional (ADB et al. 2012).[9] In the context of electricity projects, emissions from power generation are Scope 1 for the owner/operator of the power plant, emissions from electricity lost during T&D are considered Scope 2 emissions for the owner/operator of the T&D system, and the upstream and downstream indirect emissions outside the project (e.g., embedded carbon in construction materials) are Scope 3 emissions. We argue that MDBs should include Scope 3 emissions in electricity projects whenever those emissions are relevant and significant. For example, if induced benefits (e.g., energy access benefits) are included in the CBA, then induced costs should also be included (e.g., emissions associated with increased demand).

A project that is focused on reducing electricity losses would often have an NPV greater than zero, as the project could allow increased revenues from the sale of the lost electricity or reduced generation costs. The application of a shadow carbon price would then not change the NPV of the project, if the lost electricity is used to meet unmet demand (no change in overall CO_2 emissions); or it would increase the NPV, if the greater efficiency reduces the need for some fossil fuel electricity generation (consequently avoiding the costs of CO_2 emissions) (assuming constant demand). In some cases, the T&D investment, such as grid strengthening would allow for increased electricity access/demand. In this case, how the application of the shadow carbon price affects the NPV would be dependent on the magnitude of the benefits of meeting increased access/demand (e.g., greater household income, increased children's education, improved health, reduced kerosene expenditures, increased GDP and employment) and the carbon intensity of the electricity generation.

Another possible case would be that of a project that involves electricity interconnection among grids (e.g., national) that results in a change in the merit order dispatch of the power plants on both sides of the interconnector. In this case, CO_2 emissions may increase or decrease significantly depending on the carbon intensity of the plants on both sides of the interconnector. The shadow carbon pricing would then need to include this change in emissions.

It is important that a project with the highest NPV among a set of reasonable and feasible alternatives, not just a positive NPV, be selected. For example, a T&D project that reduces electricity loss on a highly carbon-intensive grid with a goal of expanding access would have a positive NPV as emissions would be reduced; however, an alternative that consisted of renewable energy generation with new distribution might have an even higher NPV inclusive of the social cost of carbon. It is possible that renewable electricity is not a viable option in a certain area, in which case, extending a carbon-intensive grid would be justified if the benefits of increased access outweigh the costs, including the costs of carbon.

While the DFIs may apply CBA slightly differently (for example, discount rates, project lifetimes, or the scope of the benefits that are quantified), it is paramount that they be transparent with their assumptions, methodology, and underlying data. See Appendix B for two examples of CBAs for electricity sector projects.

ii. Consistency with long-term decarbonization plans for the electricity sector

Every T&D investment component or overall project would need to explain credibly, in a qualitative fashion, how the project will help facilitate long-term decarbonization of the electricity sector (Box 1). Showing how a T&D project is congruent with a country's NDCs would not be sufficient in and of itself. The first set of NDCs are only for the period up to 2030 and collectively fall short of the mitigation needed to keep warming within 2°C as laid out in the Paris Agreement.[10]

The methodology that we outline would ideally be applied to larger electricity projects that would include both generation and T&D, but we recognize that sometimes an individual DFI may only finance a T&D project as part of a broader electricity-sector investment financed by a constellation of public and private sources. In the case of cross-border transmission, the investment should be congruent with the long-term decarbonization plans of all countries receiving the electricity. If the goal of a T&D investment is simply to integrate more renewables onto the grid, then it would likely be consistent with a country's decarbonization pathway.

The Paris Agreement calls for Parties to achieve "a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century" (Article 4.1) and to "formulate and communicate long-term low greenhouse gas emission development strategies" (Article 4.19). The accompanying decision text of the Paris Agreement invites Parties to communicate mid-century, long-term low GHG emission development strategies (here referred to as long-term decarbonization strategies) by 2020 (UNFCCC 2016).

To date, eight countries have submitted long-term (decarbonization) strategies: the United Kingdom, Czech Republic, France, Benin, the United States, Mexico, Germany, and Canada (UNFCCC 2018), although a number of countries have previously drafted related long-term energy plans for 2050 (e.g., Colombia, Chile, Sweden, Finland, Switzerland, Denmark, the United Arab Emirates, and India) (Ross 2018) (See Box 1.)

Box 1 | Important Elements for Any Long-Term Decarbonization Strategy

Based on emerging insights (Ross and Fransen 2017; Levin et al. 2018), there are several elements that we think should be part of any long-term decarbonization strategy:

- **LONG-TERM VISION.** A country should articulate a long-term vision for society in the strategy that frames climate action along with broader policy priorities. All of the long-term strategies submitted thus far include long-term visions, but they vary widely in their emphasis, such as transitioning to low-emissions development, strengthening climate resilience, creating jobs, and maintaining innovation and thriving economies.
- **LONG-TERM TEMPERATURE GOAL.** A country's strategy should demonstrate how it is congruent with the long-term global temperature goal of the Paris Agreement ("well below" 2°C). With the exception of Benin, all of the countries frame their strategies in the context of a long-term temperature goal, although some countries only reference 2°C (France, Mexico).
- **MODEL-BASED SCENARIO ANALYSIS.** Modeling is imperative to generate quantitative projections and to explore trade-offs, uncertainties, and assumptions about cost declines and technology trends. All but Benin and Germany included model-based scenario analysis in their long-term strategies. Qualitative approaches can complement model-based scenarios to gain deeper and richer insights, exploring how and why the necessary shifts will happen to achieve long-term goals.
- **SHORT-TERM, MEDIUM-TERM, AND LONG-TERM QUANTIFIED GHG TARGETS.** Countries should have quantitative emission targets over several periods (e.g., 2030, 2050, and post-2050), including a date for net-zero carbon emissions (recognizing the principle of common but differentiated responsibilities and respective capabilities), accompanied by plans to implement these targets. All countries but Benin have quantitative, economy-wide GHG emissions targets for 2050, while Benin has articulated a mitigation target for 2030. No country has set an explicit date for net-zero emissions post-2050, although the United States has indicated that it expects to achieve net-zero emissions decades before 2080, and Germany has stated that it is guided by the principle of reaching "extensive" GHG neutrality by 2050.
- **SECTORAL TARGETS AND INDICATORS.** All key emitting sectors should have emissions targets and indicators for the short term, medium term, and long term. Only France, Germany, and the United Kingdom have supplied quantitative targets for all sectors of the economy, including energy, although Germany's and the United Kingdom's only cover the near term (2030 and 2032). Targets are particularly critical for the energy sector, as it will need to decarbonize first to keep warming within 1.5°C/2°C. For electricity specifically, possible indicators over time would include the carbon intensity of grid-supplied electricity (tCO_2/MWh) and percentage of renewables in installed capacity (MW) or net generation (MWh).
- **THE INTEGRATION OF DEVELOPMENT OBJECTIVES.** The long-term strategies should incorporate development considerations, such as how climate action is aligned with achieving the Sustainable Development Goals (SDGs), and discuss socioeconomic themes, such as economic growth, inequality, job creation, investment, and how to support and achieve just transitions. All of the strategies discuss socioeconomic development to some degree, whether economic growth and jobs (Canada, Czech Republic, France, Germany, and the United States) or national development priorities (Benin and Mexico).
- **THE INCLUSION OF ADAPTATION PLANNING AND OBJECTIVES.** Mitigation planning should not be siloed from adaptation planning, as there are inherent synergies and linkages between long-term adaptation and mitigation pathways. Canada, the Czech Republic, France, Germany, the United States, and the United Kingdom lightly address adaptation, referring to separate adaptation planning documents, while Benin and Mexico have fully incorporated adaptation, creating a single long-term vision for low-carbon and climate-resilient development.
- **PROCESS FOR MONITORING, VERIFICATION, AND REVISION OF PLANS WITH STAKEHOLDER CONSULTATION.** A plan that is formulated over a 50-year time horizon will need to be revised with technology changes, mitigation cost declines, and new understandings of mitigation options. Good policy processes are by their nature iterative and adaptive.
- **IMPLEMENTATION PLANS.** While long-term strategies are not typically formulated as implementation plans, countries should design their strategies in a manner that can guide implementation processes and inform short-term decision-making.

Regarding the alignment of electricity T&D investments, a long-term decarbonization strategy should include model-based scenario analysis; short-term, medium-term, and long-term quantified GHG targets; and energy sector-specific quantitative goals. Thus far, only France has provided energy sector targets for both the medium term (2028) and out to 2050, which we view as a *sine qua non* for a robust long-term decarbonization strategy. Ideally, a date for net-zero emissions in the energy sector, including electricity, should also be included, but this is lacking in the current submissions. The United Kingdom comes the closest for the power sector, stating that by 2050 emissions from the sector "could need to be close to zero."

The multiple time frames of long-term decarbonization plans and the need to root them in a country's development context are important. For example, a grid strengthening and expansion project with a goal of increasing energy access may increase carbon emissions in the short-term if the grid is carbon-intensive, but also allow a long-term transition to low-carbon, renewable generation sources.

While a long-term strategy submitted to the UNFCCC would be preferable, in lieu of this, a country should have a clear sectoral plan for decarbonizing the electricity sector by 2050.

In the absence of either the incorporation of shadow carbon pricing into CBA or a long-term decarbonization plan, T&D investments not directly supporting renewable would be classified as misaligned.

Calculating Finance Volumes

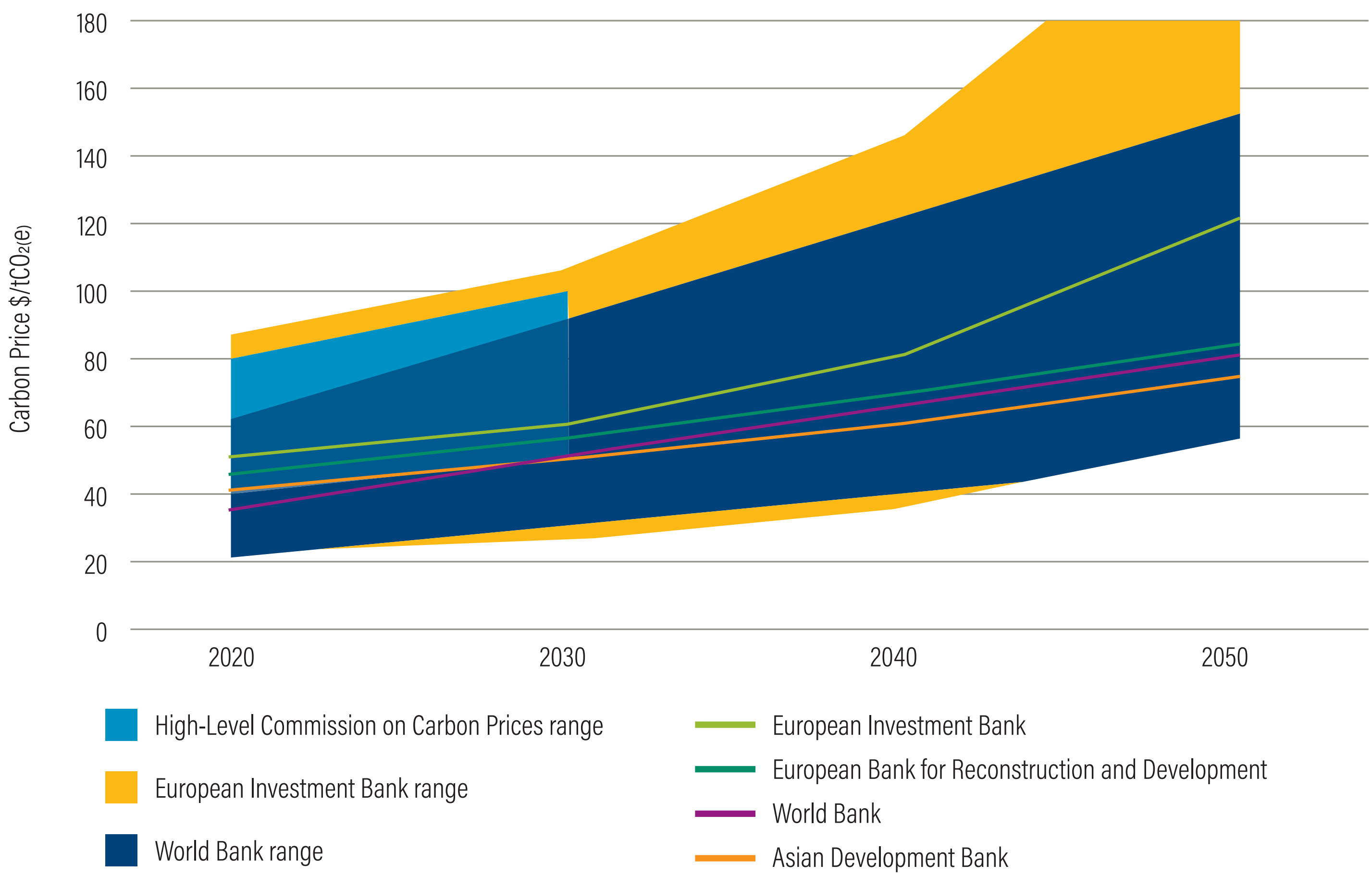
We propose hewing to the criteria in Christianson et al. (2017) for assessing projects with multiple components. For example, a T&D project with multiple components would be categorized as misaligned if it contains at least one misaligned component. Similarly, in terms of calculating finance volumes, a *pro rata* approach would be adopted, where a project's total finance is weighted by the percentage of a project that is composed of aligned elements.

Implementation of the Methodology

Our methodology for alignment is contingent on the application of a shadow carbon price and congruence with long-term decarbonization strategies. First, the inclusion of a shadow price that factors in the social cost of carbon over the life of the project is not new. Four MDBs currently apply a shadow price. To be sure, the application of shadow prices varies: Asian Development Bank guidance says a shadow carbon price "should" be applied to investments, the European Bank for Reconstruction and Development applies it only to carbon-intensive projects (Hawkins and Wright 2018), and the European Investment Bank applies it to economic analysis of all projects that have a significant CO_2 emissions profile (Howard 2018). The World Bank currently has the most ambitious standard, announcing in December 2017 that a shadow carbon price will be applied to all projects in key energy-emitting sectors where design efforts began after July 2017. The IFC started using carbon pricing in key sectors in January 2017 and will mainstream it starting January 2018 (World Bank 2017). The MDBs should ensure that the shadow carbon price has a determinant impact on project approval and begin to disclose the results of cost-benefit analyses of the selected project and alternatives in the project documents. Moreover, as all the MDBs' central prices fall below the top range laid out by the High-Level Commission on Carbon Prices (Hawkins and Wright 2018) (Figure 2), the MDB's should ratchet up ambition and adopt prices in accordance with the commission's recommendations.

Second, although most countries have yet to submit long-term decarbonization strategies, all Parties to the Paris Agreement are invited to do so by 2020. Benin is indicative of the fact that low-income countries have the capacity to develop them with international support (although Benin's strategy could be more rigorous).[11] DFIs should help recipient countries develop more robust climate-change commitments, including long-term decarbonization plans that include short-term, medium-term, and long-term quantified targets across sectors. DFIs would then need to justify in publicly available documents how T&D investments are consistent with and help to facilitate these long-term decarbonization plans.

Figure 2 | **MDB Carbon Prices Compared to the High-Level Commission on Carbon Prices Recommendations**



Note: The World Bank and European Investment Bank (EIB) both use a choice of three prices—a high, central, and low price—while the Asian Development Bank and European Bank for Reconstruction Development only use a central price. The shaded ranges (below) show the difference between the high and low carbon prices that the World Bank and EIB use in project assessments.
Source: Reproduced from Hawkins and Wright 2018.

V. DISCUSSION

Limitations of the Methodology and Project-Level Screening

The main criticism of this methodology from workshop participants and reviewers concerned using two criteria to assess Paris alignment, in particular the inclusion of the second criterion on long-term decarbonization plans. Some participants thought that it would be unrealistically restrictive and/or not implementable in the near term, as few developing countries have developed long-term decarbonization strategies or 2050 electricity sector decarbonization plans. Moreover, there can be a great divergence between the development of a decarbonization strategy and the actual implementation. But this is always the case with any development plan, climate or otherwise.[12] There is no guarantee that any commitment as part of the UNFCCC process, including NDCs, will be met. Our goal is to put forth a methodology that allows one to assess alignment of projects, given the best information that is available at the time.

The two criteria ensure that alignment considers both the near term (15 to 20 years) project economics (inclusive of a carbon price), while avoiding long-term carbon lock-in. Based on recent developments in carbon pricing and the expectation that many countries will submit long-term strategies by 2020, we do believe that trends are in the right direction. **In the absence of either the incorporation of shadow carbon pricing into CBA or a long-term decarbonization plan, T&D projects not dedicated to supporting a zero-carbon generation source will remain classified as misaligned.**

Our goal with this methodology is to be able to externally screen investments at the project level, as well as mainstream alignment of T&D investments in DFIs' operations. This project-level screen in aggregate does allow one to assess the overall T&D portfolio. There are other approaches to portfolio assessment that could be employed. For example, one fairly quick way to assess T&D investments at the portfolio level is to adopt a *pro rata* approach, where alignment is based on the current electricity mix in any country; the percentage of the aligned T&D investments in any country would be equal to the percentage of electricity generation that is zero-carbon. Our approach is more conservative, with the default that T&D investments are misaligned, unless more information is provided. The *pro rata* approach is more permissive and, in the absence of further project-specific information, would mean that alignment would be some percentage greater than zero for almost all countries. Given the urgency of the emissions-reduction challenge and the important signaling role that that MDBs play in international finance, we favor the more restrictive approach over one that would likely overestimate in many cases the amount of renewable energy T&D that is supported by a particular investment. Our more conservative approach will enhance the clarity of the signal that MDBs send to the market and should hopefully generate more impetus for DFIs to incorporate a shadow carbon price in CBA and work with developing countries to develop long-term decarbonization plans.

Of course, project-level screening of one DFI's portfolio may not be a useful representative of the overall alignment of the electricity sector in any one country. One DFI's investments may only be a small subset of the larger public and private investment. There are other approaches to assessing Paris alignment of DFI investments, such as evaluating the institution-wide sectoral strategies or country frameworks (Höhne et al. 2017). Another alternative would be to evaluate the carbon performance of utilities that may be receiving flows of international finance, through, for example, science-based targets (Science Based Targets 2018), which are based on a sectoral-decarbonization approach that translates GHG emissions targets made at the international level into appropriate benchmarks against which an individual company's performance can be compared (Dietz et al. 2017).

Development Mandates

A second major criticism of the methodology was that it could impede or otherwise penalize electricity access projects. The idea is that an economically viable project could have a negative NPV if a shadow carbon price is applied where the electricity grid is carbon-intensive. First, this is unlikely to occur, as the benefits of electricity access are likely to dominate the cost of CO_2 emissions (see Appendix B). Regardless, we do not want to give the perception that all development considerations should be based on climate change mitigation: If MDBs and DFIs want to make an investment decision based on other socioeconomic imperatives, then they should proceed, irrespective of whether the project can be labeled as climate finance and/or Paris-aligned.

Indeed, broader assessments of the alignment of investments with the Sustainable Development Goals (SDGs) are desirable. It should be emphasized, though, that climate change constrains possible development paths and that most, if not all, of the 17 SDGs are directly or indirectly related to climate action (Allen 2018). Indeed, the old paradigm that a trade-off exists between development/electricity access and low-carbon technologies has been resoundingly refuted in most places. For example, it is now widely accepted that meeting the goal of ensuring access to affordable, reliable, sustainable, and modern energy for all by 2030 (SDG 7) will not be met without renewable sources, particularly in rural areas. The International Energy Agency projects that, based on current trends and declining costs, by 2030 renewable energy sources will power over 60 percent of new electricity access (IEA 2017). But this is likely a conservative estimate of the role of renewables in addressing the urgency of energy access. Between 2009 and 2014, the cost of solar photovoltaic (PV) modules declined by three-quarters, while the cost of wind turbines declined by a third (IRENA 2015). In favorable circumstances (i.e., good resources and a secure regulatory framework), onshore wind and solar PV are cost-competitive with new fossil capacity, even without accounting for externalities (REN21 2016), and Africa is experiencing a solar revolution (GSMA 2017) where off-grid solar is the most attractive and least costly option in many rural areas (IEA 2017). Diesel generation, a common alternative for electricity access, is already more expensive than renewable generation in most developing countries (IRENA 2014). Energy access projects that focus on shifting people from kerosene/diesel use to grid-based electricity would likely result in net climate benefits.

The fact that our methodology factors in both near-term and long-term analysis allows for the possibility that certain development priorities, such as energy access, might allow for increased GHG emissions in the short term, as long as countries have longer-term plans to bend the emissions curve and move toward decarbonization.

Resilience

Our assessment only answers a limited question as to whether a T&D investment is aligned with the Paris Agreement in terms of mitigation, and climate resilience is not factored into the assessment. What a low-carbon, climate-resilient electricity system looks like is a question that needs much deeper exploration. However, there is broad agreement that climate-change impacts need to be planned for in the design of any energy system and much evidence that distributed systems, such as micro grids, have resilience benefits. A more robust, resilient electricity system will likely involve hybrid systems and an array of sources over time and space (de Coninck 2018).

The Future of the Electricity Grid

Although this is beyond the scope of our analysis, this paper leads into some fundamental questions about the future grid and whether it will continue to rely heavily on the traditional model of large central power stations (big generation) or become much more focused on distributed generation with more off-grid users and a series of linked micro- or nano-grids (Bakke 2016). There are many nascent signs that the latter is emerging. Regardless, a future smart grid that is more flexible and responsive with a large amount of variable renewable energy integrated into the system will likely see a blurring of the traditional boxes of the electricity system: supply, T&D, and end-use consumption.

For example, homeowners with solar PV systems can also be producers, not just consumers of electricity (Westphal et al. 2017). Grid edge technologies (World Economic Forum 2017) like distributed storage and electric vehicles are both electricity supply technologies and, because they help stabilize the grid and match supply and demand, have some features of T&D technologies. Indeed, electric vehicles, which play a fundamental role in the future decarbonization of transportation in most scenarios (Rogelj et al. 2018) are also batteries on wheels and break down the traditional sectoral divide between electricity generation and transportation. As the newest electric vehicles can hold enough energy to power the average U.S. home for several days and most cars sit idle 90 percent of the time, vehicle-to-grid will likely play a significant role in future storage and generation (Stapczynski 2018). We envisage that not only should T&D projects be assessed as part of a broader electricity sector appraisal, but that future assessments of Paris alignment should be holistic and multi-sectoral.

VI. CONCLUSION

Given the prominence of T&D investments in MDBs' energy portfolios, it is important that a methodology be developed that assesses the Paris alignment of T&D investments at the project level. We have put forth a fairly simple, robust methodology and decision tree. Except for the straightforward case of T&D infrastructure that directly supports a particular power plant, our methodology relies on the incorporation of shadow carbon pricing into CBA and congruence with a long-term decarbonization plan. The two criteria ensure that alignment considers both the near term (15 to 20 years) project economics (inclusive of a carbon price), while avoiding long-term carbon lock-in. Based on recent developments in carbon pricing and the expectation that many countries will submit long-term strategies by 2020, we do believe trends are in the right direction. In the absence of either, T&D projects not dedicated to supporting a zero-carbon generation source will remain classified as misaligned. We hope that this conservative approach gives impetus to all the MDBs to incorporate a shadow carbon price in CBA and work with developing countries to develop long-term decarbonization plans.

APPENDIX A. PROJECTS INCLUDED IN THE T&D SURVEY

Table A1 | **T&D Projects Approved in Calendar Year 2016 at the Asian Development Bank and World Bank**

ASIAN DEVELOPMENT BANK

PROJECT NUMBER	PROJECT NAME	COUNTRY/ REGION
43452-024	Outer Island Renewable Energy Project - Additional Financing	Tonga
45224-004	Rajasthan Renewable Energy Transmission Investment Program - Tranche 2	India
47037-005	Green Power Development and Energy Efficiency Improvement Investment Program - Tranche 2	Sri Lanka
47282-004	Energy Supply Improvement Investment Program Tranche 2 (Formerly Multitranche Financing Facility II: Energy Development 2014-2023)	Afghanistan
48434-003	Visakhapatnam-Chennai Industrial Corridor Development Program - Project 1	India
48078-002	Second Power Transmission Enhancement Investment Program - Tranche 1	Pakistan
42401-015	Power Distribution Enhancement Investment Program - Tranche 1	Azerbaijan
49216-002	Supporting Electricity Supply Reliability Improvement	Sri Lanka
44219-014	South Asia Subregional Economic Cooperation Power System Expansion - Additional Financing	Nepal
48346-002	Solar Power Development Project	Solomon Islands
46453-003	Renewable Energy Sector Project - Additional Financing	Cook Islands
49241-001	Mytrah Wind and Solar Power Development Project	India
50200-001	Triconboston Wind Power Project	Pakistan

WORLD BANK

PROJECT NUMBER	PROJECT NAME	COUNTRY/ REGION
P152822	Development Response to Displacement Impacts Project in the HoA	Africa
P149683	Liberia Renewable Energy Access Project	Liberia
P153179	Additional Financing: Kenya Electricity Expansion Project	Kenya
P155563	ENREP Additional Financing	Ethiopia
P147646	Philippines Renewable Energy Development	Philippines
P155268	GZ-Second Municipal Development Project AF	West Bank and Gaza
P153781	TZ-Rural Electrification Expansion Program	Tanzania

Table A1 | **T&D Projects Approved in Calendar Year 2016 at the Asian Development Bank and World Bank (Cont'd)**

PROJECT NUMBER	PROJECT NAME	COUNTRY/ REGION
P157096	STP Power Sector Recovery Project	São Tomé and Principe
P158709	Senegal Rural Electrification Program	Senegal
P159112	Uganda Rural Electrification	Uganda
P152755	Electricity Transmission and Reform Project	Cameroon
P156584	Modernization and Upgrade of Transmission Substations	Uzbekistan
P158655	Additional Financing to the Senegal Electricity Sector Support Project	Senegal
P151618	Electricity Access Expansion Project	Solomon Islands
P127974	North Eastern Region Power System Improvement Project	India
P133305	Uganda Grid Expansion and Reinforcement Project (GERP)	Uganda
P154805	Power Distribution Development Program-for-Results	Indonesia
P151785	MG-Electricity Sec Operations & Governance Improvement Project(ESOGIP)	Madagascar
P146933	Urban Development and Poor Neighborhood Upgrading Project	Congo, Republic of
P152659	Gambia Electricity Support Project	Gambia
P151739	Turkey Geothermal Development Project	Turkey
P153268	Access to Sustainable Energy Project	Philippines

APPENDIX B. THE APPLICATION OF A SHADOW CARBON PRICE IN ELECTRICITY PROJECT COST-BENEFIT ANALYSIS

The examples below are adapted and modified from European Investment Bank case studies (EIB 2013). While we illustrate two discrete case studies below, in reality, one electricity sector project may be part of a portfolio of projects, both renewable energy and gas-fired power plants, and extension of transmission and distribution networks. The same basic procedure for including a shadow carbon price in cost-benefit analyses would still apply across all projects and components.

Case Study 1. New Gas-fired Power Plant (Including Transmission Infrastructure)

The first case study concerns the evaluation of a hypothetical 460 MW CCGT combined cycle natural gas turbine project, including the construction of a transmission line connecting the plant to the electricity grid. The gas power plant is envisaged to replace existing capacity that is planned to be decommissioned. The costs for the project include the initial capital investment costs for construction over three years, plus annual fuel costs and operations and maintenance costs. The benefits are due to the avoided cost of generating electricity from the alternative source (coal in this case) (€196 million per year). Assuming a 4 percent discount rate and including both the social costs of CO_2 and local air pollution, the NPV of the project is €22 million (Table 1). The internal rate of return (IRR) is also shown, which is the discount rate at which the NPV equals 0. The natural gas power plant has a corresponding LCOE of 91 €/MWh (which includes both CO_2 and local air pollution), which is less than the LCOE of coal in this case of 100 €/MWh (including both external costs). So, the gas-fired power plant is the best power generation technology for this context.

Table B1 | **The Economic Returns of a Hypothetical Natural Gas Power Plant**

			CONSTRUCTION			OPERATION			
		YEAR	1	2	3	1	5	10	15
CO_2 emissions (kt)						749	749	749	749
CO_2 pricing (€/tCO_2)						29	33	38	43
Costs (€ million)									
	Capital investment		153	165	110				
	Fuel costs					105	101	103	105
	O&M costs, total					19	19	19	19
	Total (w/o CO_2 cost)		153	165	110	124	120	122	124
	CO_2 cost					22	25	28	32
	Total (w/CO_2 cost)		153	165	110	146	145	150	156
	Total (w/CO_2 + local pollution costs)		153	165	110	152	151	157	163
Benefits (€ million)									
	Avoided costs of electricity of alternative					196	196	196	196
Net benefits (€ million)									
	w/o CO_2 cost		-153	-165	-110	72	76	74	72
	w/CO_2 cost		-153	-165	-110	50	51	46	40
	w/all externalities		-153	-165	-110	44	45	39	33
NPV (w/ all externalities) (€ million)			**Discount rate**						
22			4%						
IRR (w/all externalities)									
4.7%									
LCOE (€/MWh)									
91									

Note: Data for each year not shown.
Source: EIB 2013.

Case Study 2. Reinforcement and Extension of the Transmission and Distribution Electricity Networks

This case study concerns the reinforcement and extension of the T&D, with goal of facilitating new renewable energy generation capacity and enabling the connection of 70,000 new system users. The project will also reduce network losses by 13 percent and improve reliability by 4 percent. The project benefits are derived from reducing electricity losses, improving the reliability of supply (measured as the avoided social cost of power cuts), and revenue from the provision of renewable electricity to meet the growth in demand. In this case, NPV for a 25-year lifetime is positive, and the project is projected to be profitable (Table B2).

Applying a shadow carbon price increases the NPV due to the reduction in electricity losses and the avoided costs of CO_2 emissions (calculated by the amount of electricity saved multiplied by the carbon intensity of the grid). The reinforcement of the grid also allows for increased demand, but the new generation is provided by renewable energy in this case (i.e., no net increase in GHG emissions). If the electricity grid was carbon-intensive and the T&D project allowed for increased demand, then this would result in increased CO_2 emissions; this cost, however, would need to be weighed against the substantial economic benefits of meeting unmet demand (e.g., greater business productivity, increased GDP, and employment). In this case, the right cost-benefit comparison may not be between the T&D project and the status quo, but against the T&D project and alternatives (e.g., renewable energy generation) that could also deliver the increased demand.

Table B2 | **The Economic Returns of a Hypothetical Electricity Distribution Network Project**

			CONSTRUCTION			OPERATION			
		YEAR	1	2	3	1	10	15	25
Energy Savings (TWh)			0.14	0.14	0.14	0.14	0.22	0.22	0.22
CO_2 pricing (€/tCO_2)			29	29	29	29	38	43	43
Carbon intensity of the grid (tCO_2/GWh)			300	300	300	300	300	300	300
Costs (€ million)									
	Capital investment		326	435	330				
	O&M costs, total		3	8	11	11	11	11	11
	Total		329	443	341	11	11	11	11
Benefits (€ million)									
	Reduced losses		5	8	9	9	9	9	9
	Increased reliability		0	1	1	1	1	1	1
	Revenue from supplying incremental demand		44	105	166	166	166	166	166
	Avoided cost of CO_2 emissions		1	1	1	1	3	3	3
	Total benefits		50	115	177	177	179	179	179
Net benefits (€ million)									
			-279	-328	-164	166	168	168	168
NPV (€ million)			**Discount rate**						
€1,672			4%						
IRR									
18%									

Note: Data for each year are not shown.
Source: EIB 2013.

ENDNOTES

1. CO_2e concentrations in 2100 between 430 and 480 ppm would lead to an end-of-century median temperature change between 1.5 to 1.7 °C compared to pre-industrial times.

2. The category "ambiguous" is renamed as "controversial."

3. Of course, there are embedded carbon emissions associated with the production of any infrastructure.

4. Besides renewables, nuclear would be included. While nuclear is controversial, from a climate-change mitigation perspective, its benefit is clear.

5. This would include, for example, natural gas–fired plants, hydropower, biomass, and geothermal. All the last three plants could result in direct GHG emissions.

6. A shadow price is the calculated price of a good or service for which no market price exists.

7. In lower-income countries they may actually be lower than the recommended ranges proposed here, partly because

complementary policy actions may be less costly, and the distributional and ethical issues may be more complex.

8. This would include all GHGs, not just CO_2.

9. Across the MDBs, the application of Scope 3 varies: all transportation projects (ADB); road, rail, and public transportation (EIB); when projects have material emissions (World Bank); only in case of emission savings from mitigation projects (EBRD); and no emissions generated during the first year of full operation/production if emissions are within geographic boundaries (IDB) (Germanwatch and NewClimate Institute 2018).

10. Collectively, the first set of NDCs would result in warming of 2.9–3.4°C above pre-industrial levels with a greater than 66% probability by 2100 (Rogelj et al. 2016).

11. Benin's plan was drafted in partnership with Agence Française de Développement and the UN Development Programme.

12. Future uncertainty is also an issue with how the MDBs report on climate finance. Their figures represent commitments, and there is no guarantee that the projects will produce the planned mitigation and adaptation benefits.

REFERENCES

ADB (Asian Development Bank), AFD (French Development Agency), AfDB (African Development Bank), EBRD (European Bank for Reconstruction and Development), EIB (European Investment Bank), GEF (Global Environment Facility), IDB (Inter-American Development Bank et al. 2012. "International Financial Institution Framework for a Harmonised Approach to Greenhouse Gas Accounting." http://www.worldbank.org/content/dam/Worldbank/document/IFI_Framework_for_Harmonized_Approach%20to_Greenhouse_Gas_Accounting.pdf.

AfDB, ADB, EBRD, EIB, IDB, and World Bank Group. 2017. *2016 Joint Report on Multilateral Development Banks' Climate Finance.* https://publications.iadb.org/bitstream/handle/11319/8505/2016_joint_report_on_mdbs_climate_finance.pdf.

Allen, M., O. Dube, W. Solecki, F. Aragón–Durand, W. Cramer, S. Humphreys, M. Kainumaet al. 2018. "Framing and Context." In *Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty,* edited by V. Masson-Delmotte, P. Zhai, H.O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani et al. http://www.ipcc.ch/pdf/special-reports/sr15/sr15_chapter1.pdf.

Bakke, G. 2016. *The Grid: The Fraying Wires between Americans and Our Energy Future.* New York: Bloomsbury.

Brandt, A.R., G.A. Heath, E.A. Kort, F. O'Sullivan, G. Pétron, S.M. Jordaan, and P. Tans. 2014. "Methane Leaks from North American Natural Gas Systems." *Science* 343 (6172): 733–35. doi:10.1126/science.1247045.

Bruckner T., I.A. Bashmakov, Y. Mulugetta, H. Chum, A. de la Vega Navarro, J. Edmonds, A. Faaij et al. 2014. "Energy Systems." In *Climate Change 2014: Mitigation of Climate Change.* Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler et al. Cambridge and New York: Cambridge University Press.

Carbon Pricing Leadership Coalition. 2017. *Report of the High-Level Commission on Carbon Prices.* https://www.carbonpricingleadership.org/report-of-the-highlevel-commission-on-carbon-prices/.

Christianson, G., A. Lee, G. Larsen, and A. Green. 2017. *Financing the Energy Transition: Whether World Bank, IFC, and ADB Energy Supply Investments Are Supporting a Low-Carbon, Sustainable Future.* Washington, DC: World Resources Institute. http://www.wri.org/publication/financing-the-energytransition.

Climate Bonds Initiative. 2018. "Climate Bonds Standard." https://www.climatebonds.net/standard/available.

Coninck, H. de, A. Revi, M. Babiker, P. Bertoldi, M. Buckeridge, A. Cartwright, W. Dong et al. 2018. "Strengthening and Implementing the Global Response." In *Global Warming of 1.5°C: An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty,* edited by V. Masson-Delmotte, P. Zhai, H.O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani et al. http://www.ipcc.ch/pdf/special-reports/sr15/sr15_chapter4.pdf.

Dietz, S., E. French, and B. Rauis. 2017. *Carbon Performance Assessment of Electricity Utilities: Note on Methodology.* http://www.lse.ac.uk/GranthamInstitute/tpi/wp-content/uploads/2017/06/Methodology-note-for-power-utilities-4-June.pdf.

EIB (European Investment Bank). 2013. *The Economic Appraisal of Investment Projects at the EIB.* http://www.eib.org/attachments/thematic/economic_appraisal_of_investment_projects_en.pdf.

Germanwatch and NewClimate Institute. 2018. *Aligning Investments with the Paris Temperature Goal: Challenges and Opportunities for Multilateral Development Banks.* https://newclimate.org/2018/09/28/aligning-investments/.

The Global Commission on the Economy and Climate. 2016. *The Sustainable Infrastructure Imperative: Financing for Better Growth and Development. London and Washington, DC: New Climate Economy.* http://newclimateeconomy.report/2016/wp-content/uploads/sites/4/2014/08/NCE_2016Report.pdf.

GSMA (Groupe Spécial Mobile Association). 2017. *Mobile for Development Utilities: Lessons from the Use of Mobile in Utility Pay-As-You-Go Models.* https://www.gsma.com/mobilefordevelopment/programme/m4dutilities/lessons-use-mobile-utility-pay-go-models.

Hawkins, J., and H. Wright. 2018. *How Are Development Banks Performing on Shadow Carbon Pricing?* https://www.e3g.org/library/how-are-development-banks-performing-on-shadow-carbon-pricing.

Höhne, N., C. Bals, F. Röser, L. Weischer, M. Hagemann, A. El Alaoui, D. Ecktsein et al. 2015a. *Developing Criteria to Align Investments with 2°C Compatible Pathways.* NewClimate Institute, Germanwatch, 2 Degrees Investing Initiative. https://newclimateinstitute.files.wordpress.com/2015/06/2015-06-01-investments-global-temperature-increase.pdf.

Höhne, N., F. Röser, M. Hagemann, L. Weischer, A. El Alaoiu, C. Bals, D. Eckstein et al. 2015b. *Developing 2°C Compatible Investment Criteria.* NewClimate Institute, Germanwatch, 2 Degrees Investing Initiative. https://newclimate.org/wp-content/uploads/2015/11/2criteria-final.pdf.

Höhne, N., F. Röser, M. Hagemann, C. Bals, L. Weischer, A. El Alaoui., D. Eckstein et al. 2017. *Developing Criteria to Align Investments with 2 °C Compatible Pathways. NewClimate Institute, Germanwatch, 2 Degrees Investing Initiative.* https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2017-04-05_climate-change_12-2017_investments-with-2c-compatible-pathways_0.pdf.

Howard 2018. pers. comm. European Investment Bank.

IDFC (International Development Finance Club). 2015. *IDFC Green Mapping for 2014.* https://www.idfc.org/Downloads/Publications/01_green_finance_mappings/IDFC_Green_Finance_Mapping_Report_2015.pdf.

IEA (International Energy Agency). 2017. *Energy Access Outlook 2017: From Poverty to Prosperity. Paris, France: IEA.* https://www.iea.org/publications/freepublications/publication/WEO2017SpecialReport_EnergyAccessOutlook.pdf.

IPCC (Intergovernmental Panel on Climate Change). 2014. *Climate Change 2014: Synthesis Report.* Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: IPCC. http://www.ipcc.ch/report/ar5/syr/.

IRENA (International Renewable Energy Agency). 2014. *REmap 2030: A Renewable Energy Roadmap.* http://www.irena.org/publications/2014/Jun/REmap-2030-Full-Report.

IRENA. 2015. *Renewable Power Generation Costs in 2014.* http://www.irena.org/publications/2015/Jan/Renewable-Power-Generation-Costs-in-2014.

Kempener, R., P. Komor, and A. Hoke. 2013. *Smart Grids and Renewables: A Guide for Effective Deployment.* https://www.irena.org/DocumentDownloads/Publications/smart_grids.pdf.

Kyoichi Uehara, K., C. Kern, and J.L. Koepfinger. 2015. *Future Vision of Transmission and Distribution 2030.* Paper presented at the 23rd International Conference on Electricity Distribution, June 15–18, 2015, Lyon, France.

Levin, K., T. Fransen, K. Ross, C. Elliott, M. Manion, R. Waite, E. Northrop et al. 2018. Long-Term Low Greenhouse Gas Emission Development Strategies: Approaches and Methodologies for Their Design. Input Document for the G20 Climate Sustainability Working Group. Washington, DC: World Resources Institute. https://www.wri.org/publication/designing-G20-long-term-strategies.

MDBs (Multilateral Development Banks) and IDFC (International Development Finance Club). 2015. *Common Principles for Climate Mitigation Finance Tracking.* http://www.eib.org/attachments/documents/mdb_idfc_mitigation_common_principles_en.pdf.

Navigant Research. 2018. "Transmission System Upgrades for Renewable Energy Integration." https://www.navigantresearch.com/research/transmission-system-upgrades-for-renewable-energy-integration.

Oil Change International. 2017. "Shift the Subsidies Methodology." http://priceofoil.org/shift-the-subsidies-methodology/.

Ranganathan, J., L. Corbier, P. Bhatia, S. Schmitz, P. Gage, and K. Oren. 2004. *The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard* (Revised Edition). Washington, DC: World Resources Institute and World Business Council for Sustainable Development. https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf.

REN21. 2016. *Renewables 2016 Global Status Report.* http://www.ren21.net/wp-content/uploads/2016/06/GSR_2016_Full_Report.pdf.

Rogelj, J., M. den Elzen, N. Höhne, T. Fransen, H. Fekete, H. Winkler, R. Winkler et al. 2016. "Paris Agreement Climate Proposals Need a Boost to Keep Warming Well Below 2 °C." *Nature* 534: 631. doi:10.1038/nature18307.

Rogelj, J., D. Shindell, K. Jiang, S. Fifita, P. Forster, V. Ginzburg, C. Handa et al. 2018. "Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development." In *Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty,* edited by V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani et al. http://www.ipcc.ch/pdf/special-reports/sr15/sr15_chapter2.pdf.

Ross, K. 2018. Pers. comm. World Resources Institute.

Ross, K., and T. Fransen. 2017. *Early Insights on Long-Term Climate Strategies.* Washington, DC: World Resources Institute. http://www.wri.org/publication/early-insights-long-term-climate-strategies.

Science Based Targets. "What Is a Science Based Target?" 2018. https://sciencebasedtargets.org/what-is-a-science-based-target/.

Stapczynski, S. 2018. "Your Future Home Might Be Powered by Car Batteries." https://www.bloomberg.com/news/articles/2018-04-08/cities-running-on-car-batteries-just-so-crazy-it-might-work.

Stockman, L., G. Muttitt, A. Doukas, and C. Rees. 2018. *Debunked: The G20 Clean Gas Myth.* Washington, DC: Oil Change International. http://priceofoil.org/content/uploads/2018/06/debunked_g20_eng_07_web.pdf.

UNFCCC (United Nations Framework Convention on Climate Change). 2016. *Paris Agreement.* Bonn, Germany: UNFCCC. https://unfccc.int/sites/default/files/english_paris_agreement.pdf.

UNFCCC. 2018. "Communication of Long-Term Strategies." http://unfccc.int/focus/long-term_strategies/items/9971.php. Accessed August 2018.

United Nations. 2018. "Sustainable Development Goals." https://www.un.org/sustainabledevelopment/sustainable-development-goals/. Accessed August 2018.

US IAWG (United States Inter-Agency Working Group). 2016. *Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866.* https://www.epa.gov/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf.

Westphal, M. I., S. Martin, L. Zhou, and D. Satterthwaite. 2017. *Powering Cities in the Global South: How Energy Access for All Benefits the Economy and the Environment. Washington, DC: World Resources Institute.* http://www.wri.org/publication/towards-more-equal-city-powering-cities-global-south.

World Bank. 2017. "World Bank Group Announcements at One Planet Summit." http://www.worldbank.org/en/news/press-release/2017/12/12/world-bank-group-announcements-at-one-planet-summit?CID=ECR_FB_worldbank_EN_EXT_OnePlanet.

World Economic Forum. 2017. *The Future of Electricity: New Technologies Transforming the Grid Edge.* Cologny, Switzerland: World Economic Forum. http://www3.weforum.org/docs/WEF_Future_of_Electricity_2017.pdf.

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ABOUT WRI

World Resources Institute is a global research organization that turns big ideas into action at the nexus of environment, economic opportunity, and human well-being.

Our Challenge

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our Vision

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our Approach

COUNT IT

We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT

We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT

We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.